

Implementation and Optimization of Discrete Fourier Transform (DFT) Algorithm

The Discrete Fourier Transform (DFT) generally varies from 0 to 360. There are basically N-sample DFT, where N is the number of samples. It ranges from n=0 to N-1. We can get the co-efficient by getting the cosine term which is the real part and the sine term which is the imaginary part.

$$\begin{aligned} X_k &= \sum_{n=0}^{N-1} x_n \cdot e^{-\frac{i2\pi}{N} kn} \\ &= \sum_{n=0}^{N-1} x_n \cdot \left[\cos\left(\frac{2\pi}{N} kn\right) - i \cdot \sin\left(\frac{2\pi}{N} kn\right) \right], \end{aligned}$$

Fig. 1.0. DFT Formula

Code Design

1. The header files were initialized, value of **N (Number of samples)** was initialized as 10,000. Fig. 1.0. also describes how the samples were extracted from the audio file using the ffmpeg library.

```
23 //include <math.h>
24 //include <stdio.h>
25 //include <stdint.h>
26 //include <time.h> // for clock_t, clock(), CLOCKS_PER_SEC
27
28 #define N 10000 // audio duration = 12:08 minutes, hence N = 244 X 8KHz = 1952
29
30
31 int main(int argc, char **argv)
32 {
33     // to store the execution time of code
34     double time_spent = 0.0;
35
36
37
38     //int xn[N];
39     float Xr[N];
40     float Xi[N];
41     int k = 0;
42     //float real_square;
43     //float imaginary_square;
44     float magnitude;
45
46     // Create a 20 ms audio buffer (assuming Fs = 8 kHz)
47     int16_t buf[N] = {0}; // buffer
48     int n; // buffer index
49
50     // Open WAV file with FFmpeg and read raw samples via the pipe.
51     FILE *pipein;
52     // pipein = popen("ffmpeg audio.wav -f s16le -ac 1 -", "r");
53     pipein = popen("ffmpeg -i sample_audio.wav -f s16le -ac 1 -", "r");
54     fread(buf, 2, N, pipein);
55     pclose(pipein);
56 }
```

2. After the samples have been extracted and saved to a csv file, now it's time to implement the DFT formula using the sample values in the csv file.

```

63
64     clock_t begin = clock();
65
66     for (k = 0; k < N; k++) {
67         Xr[k] = 0;
68         Xi[k] = 0;
69         for (n = 0; n < N; n++) {
70             Xr[k] = (Xr[k] + buf[n] * cos(2 * 3.141592 * k * n / N));
71             Xi[k] = (Xi[k] + buf[n] * sin(2 * 3.141592 * k * n / N));
72         }
73
74         /* Doing some few arithmetics here before saving magnitudes values */
75
76         //real_square = Xr[k] * Xr[k];
77         //imaginary_square = Xi[k] * Xi[k];
78         magnitude = sqrt(Xr[k] * Xr[k] + Xi[k] * Xi[k]);
79
80     }
81
82     clock_t end = clock();
83     // calculate elapsed time by finding difference (end - begin) and
84     // dividing the difference by CLOCKS_PER_SEC to convert to seconds
85     time_spent += (double)(end - begin) / CLOCKS_PER_SEC;
86     printf("The elapsed time is %f seconds", time_spent);
87
88

```

3. Next, we run the code without using optimization options after which we will run the code using the optimization options so as to see the time difference and to tell if the code was actually optimized and by how much time. 10 simulations were done without optimization and also 10 simulations were done using the optimization options.

Simulation 1

```

Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project- on main !4 ?3
gcc audio_signal.c -o audio_signal -lm
~/Digital-Signal-Processing-Project- on main !4 ?3
/audio_signal

```

```

size= 20kB time=00:00:00.25 bitrate= 641.5kbits/s speed=61.7x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 15.122088 seconds
~/Digital-Signal-Processing-Project- on main !4 ?3

```

Simulation without optimization

```

Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project- on main !4 ?3
gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations
-ftree-vectorize audio_signal.c -o audio_signal -lm -O3
~/Digital-Signal-Processing-Project- on main !4 ?3
c./audio_signal

```

```

size= 20kB time=00:00:00.25 bitrate= 641.5kbits/s speed=84.7x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 8.008706 seconds
~/Digital-Signal-Processing-Project- on main !4 ?3

```

Simulation with optimization

Simulation 2

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc audio_signal.c -o audio_signal -lm
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

size= 20kB time=00:00:00.25 bitrate= 641.5kbytes/s speed=76.1x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 15.017151 seconds

Simulation without optimization

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations -fvectorize audio_signal.c -o audio_signal -lm -O3
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

size= 20kB time=00:00:00.25 bitrate= 641.5kbytes/s speed= 67x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 8.040505 seconds

Simulation with optimization

Simulation 3

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc audio_signal.c -o audio_signal -lm
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

size= 20kB time=00:00:00.25 bitrate= 641.5kbytes/s speed=65.6x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 15.108588 seconds

Simulation without optimization

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations -fvectorize audio_signal.c -o audio_signal -lm -O3
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

size= 20kB time=00:00:00.25 bitrate= 641.5kbytes/s speed=83.8x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 8.099864 seconds

Simulation with optimization

Simulation 4

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc aaudio_signal.c -o audio_signal -lm
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

```
size= 20kB time=00:00:00.25 bitrate= 641.5kbit/s speed=65.1x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 15.068728 seconds
```

Simulation without optimization

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations
-ftree-vectorize audio_signal.c -o audio_signal -lm -O3
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

```
size= 20kB time=00:00:00.25 bitrate= 641.5kbit/s speed=79.8x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 7.987367 seconds
```

Simulation with optimization

Simulation 5

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc audio_signal.c -o audio_signal -lm
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

```
size= 66kB time=00:00:00.78 bitrate= 684.8kbit/s speed=70.4x
video:0kB audio:68kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 15.167609 seconds
```

Simulation without optimization

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations
-ftree-vectorize audio_signal.c -o audio_signal -lm -O3
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

```
size= 20kB time=00:00:00.25 bitrate= 641.5kbit/s speed=57.2x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 8.047286 seconds
```

Simulation with optimization

Simulation 6

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc audio_signal.c -o audio_signal -lm
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

```
size= 20kB time=00:00:00.25 bitrate= 641.5kbit/s speed=78.3x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 15.059769 seconds
~/Digital-Signal-Processing-Project-> on main !4 ?3
took 16s at 12:03:52 AM
```

Simulation without optimization

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations -ftree-vectorize audio_signal.c -o audio_signal -lm -O3
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

```
size= 20kB time=00:00:00.25 bitrate= 641.5kbit/s speed=54.6x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 8.051561 seconds
~/Digital-Signal-Processing-Project-> on main !4 ?3
took 8s at 12:08:00 AM
```

Simulation with optimization

Simulation 7

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc audio_signal.c -o audio_signal -lm
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

```
size= 20kB time=00:00:00.25 bitrate= 641.5kbit/s speed=50.1x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 15.085680 seconds
~/Digital-Signal-Processing-Project-> on main !4 ?3
took 16s at 12:10:30 AM
```

Simulation without optimization

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations -fthread-vectorize audio_signal.c -o audio_signal -lm -O3
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal
```

```
size= 68kB time=00:00:00.81 bitrate= 685.4kbit/s speed= 125x
video:0kB audio:70kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 8.008950 seconds
~/Digital-Signal-Processing-Project-> on main !4 ?3
took 8s at 12:13:02 AM
```

Simulation with optimization

Simulation 8

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc audio_signal.c -o audio_signal -lm
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal

size=      40kB time=00:00:00.48 bitrate= 672.0kbits/s speed=98.9x
video:0kB audio:42kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 15.050354 seconds

~/Digital-Signal-Processing-Project-> on main !4 ?3
took 15s at 12:16:52 AM
```

Simulation without optimization

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations -fthread-vectorize audio_signal.c -o audio_signal -lm -O3
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal

size=      30kB time=00:00:00.37 bitrate= 661.5kbits/s speed=91.6x
video:0kB audio:32kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 8.025377 seconds

~/Digital-Signal-Processing-Project-> on main !4 ?3
took 8s at 12:21:30 AM
```

Simulation with optimization

Simulation 9

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc audio_signal.c -o audio_signal -lm
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal

size=      20kB time=00:00:00.25 bitrate= 641.5kbits/s speed=65.1x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 15.021456 seconds

~/Digital-Signal-Processing-Project-> on main !4 ?3
took 15s at 12:23:16 AM
```

Simulation without optimization

```
Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-
File Edit View Terminal Tabs Help
~/Digital-Signal-Processing-Project-> on main !4 ?3
gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations -fthread-vectorize audio_signal.c -o audio_signal -lm -O3
~/Digital-Signal-Processing-Project-> on main !4 ?3
./audio_signal

size=      20kB time=00:00:00.25 bitrate= 641.5kbits/s speed=69.7x
video:0kB audio:22kB subtitle:0kB other streams:0kB global headers:0kB muxing overhead: unknown
Conversion failed!
The elapsed time is 8.012088 seconds

~/Digital-Signal-Processing-Project-> on main !4 ?3
took 8s at 12:25:45 AM
```

Simulation with optimization

Simulation 10

A terminal window titled "Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-". It shows the command `gcc audio_signal.c -o audio_signal -lm` being run, followed by the execution of the program `./audio_signal`. The output indicates a conversion failed and a total elapsed time of 15.049749 seconds.

Simulation without optimization

A terminal window titled "Terminal - fenix@fenixpi: ~/Digital-Signal-Processing-Project-". It shows the command `gcc -mcpu=cortex-a72 -mfloating-abi=hard -mneon-for-64bits -mtune=cortex-a72 -funsafe-math-optimizations -fthread-vectorize audio_signal.c -o audio_signal -lm -O3` being run, followed by the execution of the program `./audio_signal`. The output indicates a conversion failed and a total elapsed time of 8.095375 seconds.

Simulation with optimization

Result Computation

Next, we will compute the result for simulations carried out without optimization and then find the average execution time. On the other, we will also compute the result for simulations carried out with optimization and then find the average execution time.

Simulation without optimization: $15.122088 + 15.017151 + 15.108588 + 15.068728 + 15.167609 + 15.059069 + 15.085680 + 15.050354 + 15.021456 + 15.049749 = 150.750472 \text{ seconds}$

$$\text{Average Execution Time} = \frac{150.750472}{10} = 15.0750474 \text{ seconds}$$

Simulation with optimization: $8.008706 + 8.040505 + 8.099864 + 7.987367 + 8.047286 + 8.051561 + 8.008950 + 8.025377 + 8.012088 + 8.095375 = 80.377079 \text{ seconds}$

$$\text{Average Execution Time} = \frac{80.377079}{10} = 8.0377079 \text{ seconds}$$

Conclusion

From the above computations, it can be observed that the Discrete Fourier algorithm was optimized with execution 2 times faster than when it was not optimized.